

**Best Management Practices
Eye Gnat Control on Organic Farms
October 31, 2012**

Introduction

The eye gnat, *Liohippates spp.* (Diptera: Chloropidae), is considered one of the most serious nuisance pests of man and domestic animals (Mulla 1962) reducing quality of life and potentially transmitting disease agents to humans and animals (Mulla and Axelrod 1977). Eye gnats have been notable in California since the beginning of the 20th century, being coincident with large-scale agricultural food production. Heavy populations of the eye gnats have been reported in inland valley, foothill and coastal areas of California, where intensive farming occurs (Mulla 1962). It is from these cultivated areas that eye gnats migrate into areas of human activity such as residential areas, schools, parks, etc. (Mulla and March 1959).

The objective of this document is to describe Best Management Practices (BMPs) that includes all pest management practices that will mitigate eye gnat production on organic farms and have little effect on humans and the environment. This document is not limited to measures that the County could order to be used under an eye gnat ordinance. In particular, the use of organic pesticides on food crops, or the use of conventional or organic pesticides on non-food buffer crops, is not measures the County could order under the proposed ordinance. They are effective measures that an organic farmer could choose to use in appropriate circumstances.

The following is a step-by-step method of developing BMPs and validating their effectiveness. In addition, although it is anticipated that there will be no discernable negative environmental effects, each BMP contains a description of the potential environmental effects due to the change in practice necessary to reduce eye gnat populations on an organic farm.

- Gather scientific background information regarding specific problematic practices and alternatives by reviewing the scientific literature
- Seek technical assistance from UC Cooperative Extension experts that can address problematic practices and alternatives
- Scientific analysis of feasibility of the methods, limitations, and environmental effects as shown by scientific literature or practice
- Select scientifically valid BMPs for implementation
- Consider alternative BMPs for methods that have limitations
- Provide alternative/site specific BMPs to allow for differences in production types and topography of each farm/facility
- Implement BMPs
- Reevaluate BMPs

For each stage of the insect, different tactics are used to affect a population. Reduce food source, modify the food source, make habitat inhospitable, repel or exclude, use

toxicants, physically remove a portion of the population, etc. The following general categories of control options may be successful in minimizing eye gnat populations:

- Physical control or exclusion options
- Cultural control options
- Chemical Control options
- Biological control options
- Various combinations of the options above

Summary of Effective BMPs against Eye Gnats

Each method has an impact on eye gnat production by reducing some proportion of the population as evident from the discussion above.

- Reduce the amount or stop tilling fresh or dry organic matter into the soil entirely. Eye gnat reduction from tilling will be proportional to the reduction in tillage.
- Barrier crop treated with conventional/synthetic insecticides in rotation
- Physical barrier (36 inch erosion or silt barrier or fence at minimum)
- Solarization by solid plastic covers/row covers to exclude adult emergence
- Mass Trapping/Removal Trapping
- Selected organic pesticides that are deemed effective against select eye gnat life stages
- Fallow or dry period
- Use of fertilizer/amendment that is not eye gnat producing
- Apply liquid feed fertilizers
- Apply unprocessed fertilizers/incorporate raw manures during the period when eye gnat populations are relatively low and inactive – December to February.

PHYSICAL CONTROL OR EXCLUSION OPTIONS

Method	Description of Practice	Discussion of Practice and Scientific Background Information	Anticipated Environmental Impact
<i>Barriers</i>	A fence that excludes eye gnats from mitigation.	A fence that excludes eye gnats from migrating from farms is a viable option for mitigation. Exclusion fencing has been used in the management of other fly pests on conventional farms. It has been shown that fencing, especially with an overhang, will dramatically reduce the immigration of cabbage flies into plantings. The opposite is certainly true, that the number of eye gnats emigrating from farms will also be reduced. Screening material can be used as long as the screen hole sizes are large enough to exclude eye gnats. A similar sized fly, <i>Liriomyza trifolii</i> Burgess, can be excluded using a screen with hole sizes of 400µm (Bethke and Paine 1990). For complete exclusion, the height of the barrier needs to be 12.4'. In most cases, that is impractical. However, a portion of the population can be excluded using inexpensive 36 inch erosion or silt barrier or fence.	There is no anticipated environmental impact due to the use of an 36 inch erosion or silt barrier or fence to exclude eye gnats. Organic farms are under intense scrutiny by organic certifiers to exclude roving animals from organic produce production due to urine and feces contamination. In addition, farms are under scrutiny for water contamination due to silt production. Therefore, the 36 inch erosion or silt barrier or fence may be beneficial to organic farmers for additional reasons other than eye gnat control. The 36 inch erosion or silt barrier or fence may be visible from surface streets, but will not cause any negative impacts on the environment.
<i>Mass Trapping or Removal Trapping of Adults</i>	Physically removing insects from the population	Mass trapping or removal trapping is a common practice for insect vectors (Day and Sjogren 1994). The majority of the vector control surveillance programs presently in use throughout the world use some form of attractant (Day and Sjogren	Eye gnat collar traps are designed to capture eye gnats using an attractive putrefied egg bait (Mulla and Axelrod 1977) that does not contain a toxicant. Mammals are not attracted to the putrefied egg bait, and in fact is used in many commercially

		<p>1994). It is well known that adult eye gnats are attracted to a variety of putrefying proteins (Burgess, 1951). In particular, fermented aqueous suspension of chicken whole-egg powder is highly attractive to female eye gnats (Mulla et al, 1960), but putrefied egg bait possesses highly objectionable odors (Mulla, 1973). Putrefied egg bait is placed in collar traps for mass trapping.</p>	<p>available animal repellents. Although the traps do attract other flies (Muscidae, house flies, lesser house flies, etc.) they are typically considered a pest and not a beneficial organism. In addition, the traps are designed in such a way that only allows eye gnat sized flies to enter, which reduces the probability of capturing other fly species. Beneficial wasps are also not attracted to the eye gnat trap bait and are not found in traps. Eye gnat traps are placed within farm property at recommended densities and at a height of about 36 inches attached to a stake and are typically not visible from surface streets. Therefore, there is no anticipated effect on the environment by the presence of eye gnat traps or trap captures. Although the putrefied egg bait has an objectionable odor, it is localized around the traps and is not noticeable from distances further than 10 feet from the traps. Therefore, the odor will not be perceptible by the public nor will it cause any undue affect to farm workers.</p>
<i>Emergence Exclusion</i>	<p>Applications of soil applied plastics, row covers, permeable plastic sheets that do not allow adult eye</p>	<p>Agricultural plastics are available to help growers improve quality or increased yields by suppressing weeds and retaining moisture (McCraw and Motes 2007). It follows that if the soil is covered, eye gnats cannot emerge. However, row covers will</p>	<p>Row covering plastics placed on the organic farm is a very common practice and poses no undue environmental impact. Impermeable plastics are also common organic farm practice and used for sterilization/solarization of the soil and also</p>

	gnats to escape from soil	have holes where plants are exposed and could offer a potential source of eye gnat emergence. The overall population should be reduced proportionally to the area covered. Other holes and areas where irrigation pipes and tubing enter the plastic may also be a source of eye gnat production. Plastics covering fallow ground will not allow any adult eye gnat emergence.	poses no undue environmental impacts. Permeable plastics allow water and air transfer to soils, but will not allow eye gnat emergence and also poses no undue environmental impacts. Soil temperatures and decomposition (soil microbial composition) are increased due to plastic covers, however, temperatures and decomposition rates will return to normal once the plastic has been removed. Any loss in organic matter can be replaced during the next cropping cycle or supplemented using liquid feed/injected fertilizer during the cropping cycle. When complete, the plastics can be recycled so that it does not impact the environment during disposal. The plastic covers will be visible, but should pose no undue risk to animals or the environment.
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CULTURAL CONTROL OPTIONS

Method	Description of Practice	Discussion of Practice and Scientific Background Information	Anticipated Environmental Impact
<i>No till</i>	The halt of tilling or turning organic matter back into the soil	Non-cultivation as emphasized by scientists (Legner and Bay 1970) has been and continues to be the principal requisite to gnat abatement. While changes to crop cultivation (in particular reduced need for tilling) in conventional farming reduced eye gnat production to below nuisance thresholds in most areas (Mulla, personal communication), the recent increase in organic farming which utilizes crop tilling to maintain soil health has resulted in a return of eye gnat flies (Bethke et al. 2010). Eye gnats breed heavily in damp, sandy soils where plant and animal materials are incorporated during tillage. Eye gnat production, however, varies with organic matter source and amount. Mulla and Axelrod (1973) demonstrated that various leafy materials incorporated into soil medium supported eye gnat development and emergence. Grassy monocots such as Bermuda grass and corn stubble, however, produced the fewest eye gnats.	There is no anticipated environmental impact due to the halt of tilling or turning of organic matter (weed or crop residues) into the soil.
<i>Change Irrigation Practices</i>	Reducing the amount of water used on the farm	Irrigation is a key component in eye gnat population production (Mulla 1961). Eye gnat populations may potentially be	Reducing water use is beneficial generally and has no anticipated environmental impact. Drip tape and drip emitters are

	and on the crop by utilizing drip emitters or drip tape	reduced if overhead irrigation is converted to drip tape or drip emitters. Drip irrigation reduces the amount of water used and irrigation tubing that is buried increases water retention. In addition, drip irrigation under plastic row covers will retain water and reduce need.	common practice in agricultural settings including organic farms.
<i>Fallow or dry period</i>	A farm cycle free of crop production. A farm cycle free of any irrigation.	If organic cropping cycles cease for any length of time, there will be a concomitant halt in eye gnat population development (Bethke et al. 2010). There is some indication that eye gnat eggs can senesce and rehydrate following a dry period (Legner and Bay 1970), but eye gnat production will be stymied by the inclusion of a dry period possibly reducing the number of generations of eye gnats in a year and hence reducing the overall population levels.	There is no anticipated environmental impact due to a fallow or dry period in organic farming. There is a greater impact on the environment that can be assumed by the addition of tilling, fertilizing and irrigation practices rather than its halt.
<i>Proper Fertilizer use</i>	Fertilizers need to be processed or liquid feed, not raw manure or raw organic matter. If unprocessed, they need to be added to the soil when eye gnats are not present	Mulla and Axelrod (1973) found that fertilizers such as raw steer manure, chicken manure, or blood meal produced substantial numbers of eye gnats, and that eye gnat production was directly proportional to the amount of steer and chicken manure added. They noted, however, that nitrohumus, ammonium sulfate and processed steer and chicken manure produced almost no eye gnats. Mulla and Axelrod (1973) recommend that	There is no anticipated environmental impact due to the use of processed fertilizers. Nor are there any anticipated impacts due to the addition of raw materials during eye gnat free periods.

		farmers apply fertilizers/incorporate fertilizers during the period when eye gnat populations are relatively low and inactive – December to February.	
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CHEMICAL CONTROL OPTIONS

Method	Description of Practice	Discussion of Practice and Scientific Background Information	Anticipated Environmental Impact
<i>Organic Registered Insecticide Use</i>	Treat the crop with products toxic to adult eye gnats. Treat the soil with products that are toxic to the larval stage.	Pesticides have been an effective method of eye gnat control for more than 50 years. Various certified organic pesticides have proven effective. Spinosad (Entrust, Dow AgroSciences) can cause very good mortality when ingested, but has little contact activity. In addition, biologicals have been tested with few showing efficacy (Hall et al. 1973). <i>Beauveria bassiana</i> has shown some efficacy against eye gnats (Hall et al. 1972) but needs further study with current formulations such as Mycotrol-O. Various formulations of <i>Bacillus thuringiensis</i> (Bt products) and parasitic nematodes, <i>Steinernema fetae</i> , have also been tested with no appreciable mortality to eye gnat larvae (Bethke et al. 2008). Contact oils such as rosemary oil (Ecotec, Brandt) will be somewhat effective against adult eye gnats (J. Bethke unpublished data).	Pesticides that are recommended for use on organic farms have been extensively tested and reviewed for environmental effects by the EPA and the California Department of Pesticide Regulation prior to sale. Use of these pesticides will not negatively impact the environment if used legally according to label instructions. Some pesticides warn of potential toxicity to classes of organisms. Site circumstances should be considered prior to using these pesticides. Pesticides will also not impact workers when used properly, and since natural enemies of eye gnats are nearly non-existent, pesticides will not have an effect on natural enemies. Therefore, there is no anticipated significant effect on the environment by the use of pesticides. Nevertheless, the proposed ordinance would not authorize the County to require the use of any pesticide, including organic pesticides.

BIOLOGICAL CONTROL OPTIONS

Method	Description of Practice	Discussion of Practice and Scientific Background Information	Anticipated Environmental Impact
<i>Natural enemies</i>	Augmentative or inundative release of natural enemies of eye gnats.	Four parasites were observed attacking eye gnat soil-borne larvae and pupae (Bay et al. 1964); however, field parasitism rates were exceptionally low (<1%). Surveys of potential predators provided a substantial list, but failed to demonstrate the ability of any one species to have an impact on eye gnats (Legner et al. 1971). One species of rove beetle (Staphalinidae) in the tribe Oxypodini was observed predating on eye gnat pupae in the Coachella Valley (Moore 1965).	There is no anticipated effect on the environment by the use of natural enemies.

VARIOUS COMBINATIONS OF OPTIONS

Method	Description of Practice	Discussion of Practice and Scientific Background Information	Anticipated Environmental Impact
<i>Conventionally Treated Barrier Crop</i>	Addition of a crop that is treated with conventional synthetic insecticides, borders the farm, and is perpendicular to the affected residents	A barrier or trap crop is a planting of a crop that borders the marketable commodity and is a preferred host of eye gnats. Eye gnats are attracted to a preferred crop and will have to proceed through the barrier crop while migrating to residential neighborhoods. The border should be planted directly between the farm and affected community (See Bethke et al. 2009) and should be of sufficient width (no less than 20') and height (no less than 24") to ensure the flies will contact the barrier crop and pesticide treated foliage prior to exiting the farm. It's been demonstrated that Alfalfa is an excellent environment for eye gnat population growth (Mulla and Axelrod 1973). Typically, the barrier crop is treated with an effective pesticide for eye gnat mitigation control (See Bethke et al 2010). Even though the barrier crop is treated with conventional insecticides, the balance of the crop can be marketed as organic. It's been demonstrated that insecticides and repellents are effective control measures (Mulla 1963, Chansang and Mulla 2008) for eye gnats and eye flies.	<p>The planting of a barrier or trap crop is not a new practice for farming operations and the crop will not have any anticipated impacts on the environment any more so than the actual planted marketable crop.</p> <p>The three recommended pesticides have been extensively tested and reviewed for environmental effects by the EPA and the California Department of Pesticide Regulation prior to sale. Use of these three pesticides will not negatively impact the environment if used legally according to label instructions. They will also not impact other organisms or workers on the rest of the farm, only the barrier crop. The environmental impact of these three pesticides are listed in Table 1. The proposed ordinance would not authorize the County to require the use of pesticides on barrier crops.</p>

		The trap crop should be treated weekly for best results: acephate or malathion which are organophosphates, and cyfluthrin a pyrethroid. Products should be rotated between the organophosphates and the pyrethroid so that no single chemical class is applied in succession. Resistance development is common in eye gnats (Georghiou and Mulla 1961, Axtel and Edwards 1970a, 1970b).	
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REFERENCES CITED

- Axtell, R. C. and T. D. Edwards.** 1970a. Susceptibilities of adult *Hippelates* eye gnats to insecticidal deposits. Department of Entomology. North Carolina State University, Raleigh 27607. 1186-7.
- Axtell, R. C. and T. D. Edwards.** 1970b. Susceptibilities of adult *Hippelates* eye gnats to insecticidal fogs. Department of Entomology. North Carolina State University, Raleigh 27607. 1184-5.
- Bethke J. A. and T. D. Paine.** 1991. Screen Hole Size and Barriers for Exclusion of Insect Pests of Glasshouse Crops. J. Entomol. Sci. 26(1): 169-177.
- Bethke, J. A., B. Vander Mey, T. P. Salmon, & V. J. Mellano.** 2008. Biology and Control of the Eye Gnat *Liohippelates collusor*. Final Report San Diego County Eye Gnat Research and Education Project 2008, County Contract #523836. 29pp. available online: [http://cesandiego.ucdavis.edu/Floriculture - Nursery/San Diego County Eye Gnat Research and Education Project/](http://cesandiego.ucdavis.edu/Floriculture_-_Nursery/San_Diego_County_Eye_Gnat_Research_and_Education_Project/)
- Bethke, J. A., B. Vander Mey and I. DeBonis.** 2009. Biology and Control of the Eye Gnat *Liohippelates collusor*. Final Report: San Diego County Eye Gnat Research and Education Project 2009. County Contract #532716. Also available online.
- Bethke, J. A., B. Vander Mey and I. DeBonis.** 2010. Biology and Control of the Eye Gnat *Liohippelates collusor*. Final Report: San Diego County Eye Gnat Research and Education Project 2010. County Contract #532716 Amendment #1. Also available online.
- Burgess, R. W.** 1951. The life history and breeding habits of the eye gnat, *Hippelates pusio* Loew, in the Coachella Valley, Riverside County, California. Am. J. Hyg. 53: 164-177.

- Day, J. F. and R. D. Sjogren.** 1994. Vector control by removal trapping. *Am. J. Trop. Med. Hyg.*, 50(6):126-133.
- Georghiou, G. P. and M. S. Mulla.** 1961 Resistance to chlorinated hydrocarbon insecticides in the eye gnat, *Hippelates collusor*. *J. Econ. Entomol.* 54(4):695- 8.
- Hall, I. M., Dulmage, H. T., and Arakawa K. Y.** 1972. The susceptibility of the eye gnat *Hippelates collusor* to entomogenous bacteria and fungi. *Journal of invertebrate pathology.* 19: 28- 31.
- Legner, E. F., and Bay E. C.** 1970. Dynamics of *Hippelates* eye gnat breeding in the southwest. *California Agriculture.* 4:6.
- McCraw, D. and J. E. Motes.** 2007. Use of Plastic Mulch and Row Covers in Vegetable Production. Oklahoma Cooperative Extension Fact Sheets. HLA-6034. 1-5.
- Moore., L. D.** 1965. A coleopterous parasite of *Hippelates* eye gnats of the family Staphinidae. *Proceedings and papers of the annual conference of the California Mosquito Control Association.* 33:61-2.
- Mulla, M. S.** 1961. Control of *Hippelates* gnats with soil treatments using organochlorine insecticides. *J. Econ. Entomol.* 54(4): 636- 41.
- Mulla, M. S.** 1962. The breeding niches of *Hippelates* gnats. *Ann. Ent. Soc. Amer.* 55(4): 389-393.
- Mulla, M. S.** 1963. An ecological basis for the suppression of *Hippelates* eye gnats. *J. Econ. Entomol.* 56(6): 768- 70.
- Mulla, M. S.** 1965. Biology and control of *Hippelates* eye gnats. *Proceedings 33rd Annual Conference Mosquito Control Association.* Pg. 26-8.
- Mulla, M. S.** 1966. Oviposition and Emergence Period of the Eye Gnat *Hippelates collusor*. *J. Econ. Entomol.* 59(1): 93-96.
- Mulla, M. S., and Axelrod H.** 1973. Organic wastes and soil additives as producers of *Hippelates* eye gnats (Diptera-Chloropidae). *Environmental Entomology.* 2: 409-13.
- Mulla, M. S., and Axelrod H.** 1977. Attractancy of putrefied animal and plant proteins to the eye gnat *Hippellates collusor* (Diptera: Chloropidae). *J. Med. Entomol.* 133(4-5): 497- 500.
- Mulla, M. S., and March R. B.** 1959. Flight range, dispersal patterns and population density of the eye gnats, *Hippelates collusor*. *Ann. Ent. Soc. Amer.* 52(6): 641-6.
- Mulla, M. S., M. J. Garber, H. Axelrod and F. G. Andrews.** 1966. Control of *Hippelates* eye gnats with herbicidal oils. *J. Econ. Entomol.* 59(3): 552- 5.

Table 1. Three conventional or synthetic insecticides described for their environmental impacts.

Pesticide	Chemical Class (IRAC)	Site/crop	Environmental Hazards
Acephate	Organophosphate (1B)	Head Lettuce, Peppers, Peppermint, Spearmint, Soybeans, Beans, Brusselsprouts, Cauliflower, Celery, Turf	This pesticide is toxic to birds. For terrestrial uses, do not apply directly to water, or to areas where surface water is present or to intertidal areas below the mean high water mark. Do not contaminate water when cleaning equipment or disposing of equipment washwaters. This product is highly toxic to bees exposed to direct treatment or residues on blooming crops or weeds. Do not apply this product or allow it to drift to blooming crops or weeds while bees are actively visiting the treatment area.
Malathion	Malathion (1B)	Asparagus, Beets, Broccoli, Brussel sprouts, Cabbage, Carrot, Cauliflower, Celery, Eggplant, Endive, Collards, Kale, Hops, Cucumber, Leaks, Lettuce, Peppers, Mustard Greens, Radish, Spinach, Parsley, Strawberries, Tomatoes, Turnip Greens	This product is toxic to aquatic organisms, including fish and invertebrates. This product may contaminate water through drift of spray in wind. This product has a high potential for runoff after application. Use care when applying in or to an area which is adjacent to any body of water, and do not apply when weather conditions favor drift from target area. Poorly draining soils and soils with shallow water tables are more prone to product runoff that contains this product.
Cyfluthrin	Pyrethroid (3)	Alfalfa, Corn (field, pop, seed), Cotton, Grasses, Peanut, Sorghum,	This pesticide is extremely toxic to fish and aquatic invertebrates. For terrestrial uses, do not apply directly to water, to areas where surface water is present or to

Soybean, Sugarcane,
Sunflower, Barley,
Buckwheat, Millet (Pearl
And Proso), Oat, Rye,
Triticale And Wheat,
Brassica (Cole) Leafy
Vegetables, CG 5,
Cucurbits, CG 9, Fruiting
vegetables, CG 8, Leafy
vegetables, CG 4, Dried
Shelled Legume
Vegetables, CSG 6C, Pea,
Southern, Potato, and
other tuberous and corm
vegetables, CSG 1C,
Carrot and Radish, Sweet
corn.

intertidal areas below the mean high water mark. Do not
apply when weather conditions favor drift from treated
areas. Drift and runoff from treated areas may be
hazardous to aquatic organisms in neighboring areas. Do
not contaminate water when disposing of equipment
washwater or rinsate. Apply this product only as
specified on this label. This pesticide is highly toxic to
bees exposed to direct treatment or residues on
blooming crops or weeds. Do not apply this product or
allow it to drift to blooming crops or weeds on which
bees are actively foraging. Additional information may be
obtained by consulting your Cooperative Extension
Service.

Table 2. Organic and conventional pesticides recently tested against eye gnats in the laboratory (Bethke et al. 2008-2011).

Trade Name	Manufacturer	Active Ingredients	Rate	% Mortality	Trial Unit
Ecotec EC*	Brandt Consolidated	Rosemary Oil 10% plus Peppermint Oil 2%	4 pts/a foliar	Adult 100	Vial
				Larvae (2X) 54	Jar
Entrust/Naturalyte*	Dow AgroSciences	Spinosad 80%	3 oz/a foliar (max 9 oz/crop)	Adult 100	Vial
				Larvae 40	Tray
Neemix 4.5*	Certis	Azadirachtin 4.5%	2 gal/ 4.5gal/a for subsurface pests	Adult 86	Vial
Matratec EC* (Herbicide)	Brandt Consolidated	Clove Oil 50%	10% v/v	Larvae (2X) 30	Jar
Pyrellin EC	Webb Wright	Pyrethrins .60%	2 pints/a	Larvae 2.5	Jar
		Rotenone .50%			
		Other Resins .50%			
Sevin SL	Bayer Crop Science	Carbaryl 43%	2 qt/A	Adult 100	Vial
				Larvae 100	Jar
Tempo	Bayer Crop Science	Cyfluthrin 11.8%	16 ml/g	Adult 100	Vial
Malathion	Loveland	Malathion 80%	1.25 gal/100 g	Adult 100	Vial
Gnatrol WDG*	Valent	<i>Bacillus thuringiensis israelensis</i> 37.4%	26 oz/100 gallons	Larvae 63	Jar

*Certified organic pesticides.

Jar trials were conducted in rearing media in quart sized mason jars.

Tray trials were conducted in farm soil in a seedling tray.

Vial trials are conducted in small, capped glass vials coated with toxicant.